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Abstract

Presented in this paper is a cold formed steel load distribution system developed by iSPAN Systems LP that enables the installation of floor joists without the need to align them with the supporting wall studs. The floor joists are supported by a shear connection attached to a cold formed steel perimeter distribution member. In addition to the load distribution aspect, the system results in a simplified lateral design approach. An experimental verification study was carried out to establish the load distribution capability of the system, resulting in a simplified procedure to determine the connection requirements and load transfer characteristics to the wall studs.

Introduction

Cold formed steel construction has been used increasingly in the past two decades, particularly for low to midrise residential and light commercial construction. Many benefits are realized from using light steel construction including a high speed of construction, good durability, and because of its lighter weight with respect to other methods of construction, there are less demands on the wind/seismic force resistance systems as well as the foundations. Historically, buildings are framed using platform construction and inline framing (Figure 1), where joists are framed on top of a wall and are aligned with studs above and below at the floor to wall connection. According to AISI S200 [1]: *"Each joist, rafter, truss, and structural wall stud (above and beneath) shall be aligned vertically"* as specified. *"The alignment tolerance shall not be required when a structural load distribution member is specified…"*

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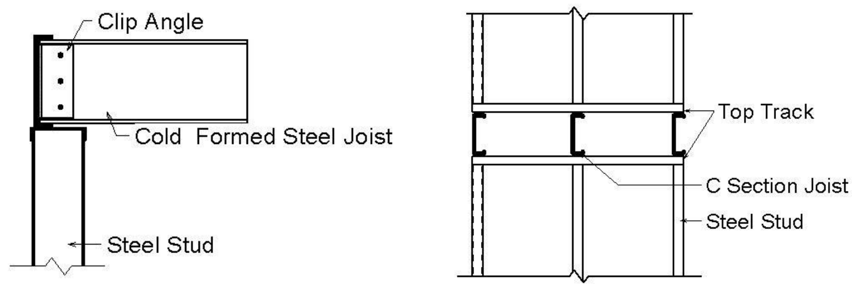


(a) Platform Framing **(b) In-line framing**

Figure 1 – Traditional Framing Methods

In-line construction is used because the top track of a wall is generally not sized to resist the point loads from the joist reactions. However, in-line construction introduces several challenges, such as:

- Joist to stud spacing mismatch: The advent of stronger and stiffer joists has led to floors that can be framed at larger spacing, while typical stud spacing in walls is typically 12" or 16" o.c. Spacing joists further apart can significantly increase cost effectiveness as a result of less steel usage [2] and fewer components to install. Further, in higher load areas such as assembly areas, joists may need to be spaced closer (say at 12" o.c.). Coordinating stud spacing with joist spacing adds complications to a design and can reduce the overall efficiency of the building.
- Special detailing requirements: In-line framing results in stud end reactions being transferred through joists into the stud below, resulting in bearing stiffeners that must be properly sized and fastened to each stud. Further, at hold down locations for shear wall panels, special detailing must be used in order to transfer the chord stud reactions through the floor plenum.
- Additional studs at extra joist locations: While consistent joist spacing is typically maintained throughout a floor, it is common for joists to be added between normally spaced joists, for example in locations of floor openings. Given that walls must be erected prior to floors, all studs and joists must be located prior to installation. As well, drawings must be provided to ensure that studs will be in place at the correct locations to receive the joists, both normally spaced and added. This coordination requires considerable design time and often expensive and specialized software.

Distribution Members and Ledger Framing

The inefficiency and complexity of executing in-line framing has led to the use of several different load distribution members (Figure 2).

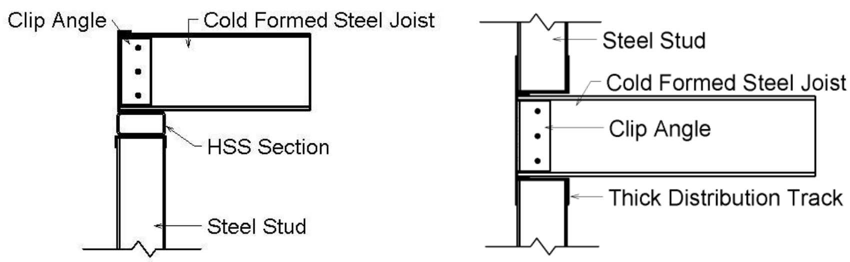


Figure 2 – Examples of Load Distribution Members

While the distribution members above eliminate the complexity of coordinating studs and joists prior to wall fabrication, they tend to add significant cost to a cold formed steel structure. Further, they do not eliminate the special detailing requirements discussed above.

Another approach to framing a floor to wall connection uses a steel ledger fastened to the inside face of the wall. This method is herein referred to as “Ledger Framing” and offers the following advantages:

- eliminates the need to coordinate stud and joist locations and significantly reduces design and coordination complexities,
- eliminates the need for special detailing to resist web crippling and to transfer shear wall chord stud loads through the floor plenum,
- facilitates different joist spacing compared to stud spacing, and
- provides a more direct load path for both vertical shear wall to shear wall connections, as well as horizontal diaphragm to shear wall connections.

The result is a simplified and more efficient construction method.

Design of Ledger Framing System

Three common methods that are currently used by designers to analyse a ledger framed system are described below:

1. Conservative Approach: To design the stud for the full load of the joist reaction assuming that, in the case that the stud and joist are aligned, the entire joist reaction is carried by the stud. This can be idealized by assuming the ledger track is a continuous beam over pinned supports, which is conservative because it assumes the studs have infinite axial stiffness. This approach leads to the following stud design values of reaction and moment:

$$\mathbf{R_s = R_j} \tag{1}$$

$$\mathbf{M_s = R_j \times e} \tag{2}$$

2. Unconservative Approach: To design the stud based on a uniform load that is induced by the floor, which can be idealized as a continuous beam acting over elastic spring supports. However, it is unconservative because it assumes that the flexural stiffness of the ledger track is rather large relative to the axial stiffness of the studs. The resulting reaction and moment values are as follows:

$$\mathbf{R_s} = \frac{\boldsymbol{s_s}}{\boldsymbol{s_j}} \times \mathbf{R_j} \tag{3}$$

$$\mathbf{M_s = R_s \times e} \tag{4}$$

3. Analytical Approach: To design the stud based on the results of an analytical analysis of the ledger as a continuous beam supported by the studs. This yields the most accurate results, but involves a greater effort. Further, it becomes more difficult to include other system effects such as the load distribution of the deck, as well as the eccentricity introduced by one sided clip angle connectors (Figure **3**(b)), if required. Here the resulting reaction and moment values are as follows:

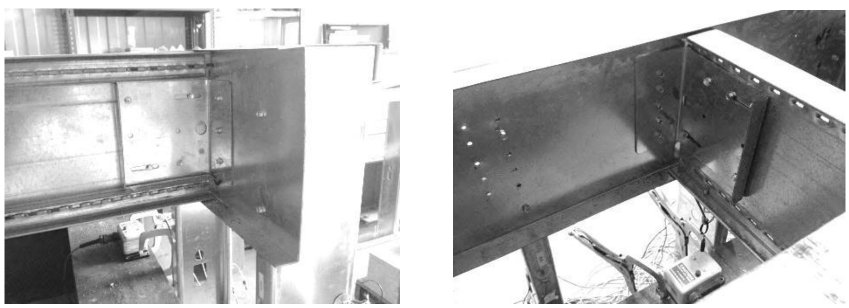
$$\mathbf{R_s = C \times R_j} \tag{5}$$

$$\mathbf{M_s = R_s \times e} \tag{6}$$

In Equation (5), the factor C is influenced by a variety of factors, including stud type, height, and spacing, joist spacing, distribution member type, subfloor type (due to load distribution through the subfloor), and connection type. The following sections are a summary of initial testing that was conducted at iSPAN Systems LP's Dr. R.M. Schuster Research Laboratory. The purpose of the test program was to confirm the load distribution capability of a steel track section.

Test Methodology

The 9 1/2" deep floor system was constructed with 3 joists at a spacing of 16" o/c that were framed into the wall using a 9 1/2", 0.0710", 50 ksi track section and using 9 1/2" TotalJoist end connectors, as shown in Figure 3(a). The end connectors were fastened with four screws into the joist and five screws into the track. All of the screws were 12-14x1" HWH TEK/3.

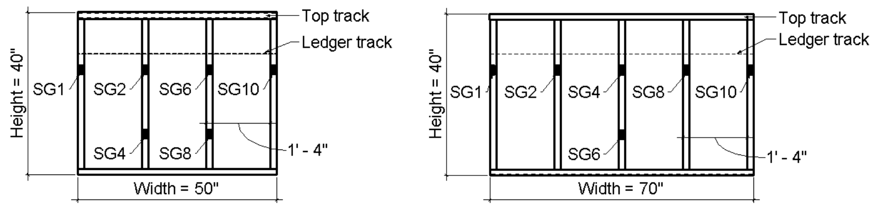


(a) Joist to Wall Assembly **(b) Connector to Joist and Track**

Figure 3 - Framing into Stud Wall

The center joist web was reinforced with ¾" OSB to ensure that no failure would occur in the joist. A ¾" OSB subfloor was fastened to each joist at 6" o/c to provide lateral stability of the joists.

Five stud and four stud walls were constructed using 600S162-68 studs and the walls were constructed with 40" tall studs located at 16" o/c. A standard 600T125-68 track section was installed at the top and bottom of the wall. The wall construction is illustrated in Figure 4.



(a) 4 Stud Wall **(b) 5 Stud Wall**

Figure 4 - Wall Type with Strain Gauge Locations

A 950T125-68 ledger track was mounted on the face of the wall, allowing the joists to frame into it as shown in Figure 3(b). Two #12-14x1" HWH T/3 screws were used to connect the ledger track to each stud 2" from the top and bottom of the track.

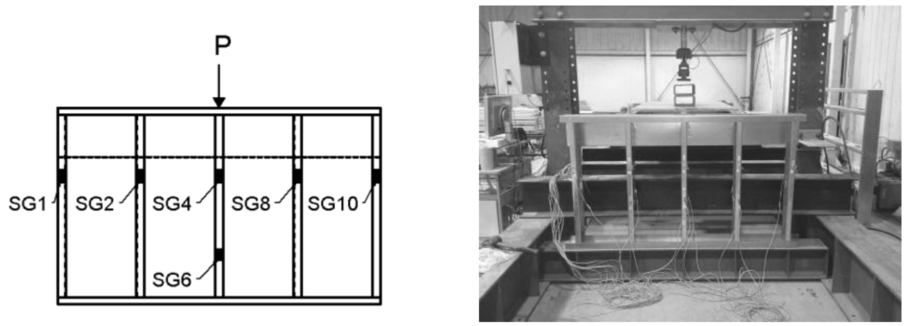
Three different wall assemblies were tested using four and five stud walls, as shown in Figure 5.

Test 1 – 0" Load Offset: was a five stud wall with the center joist loaded and with the screws directly fastened to the center stud.

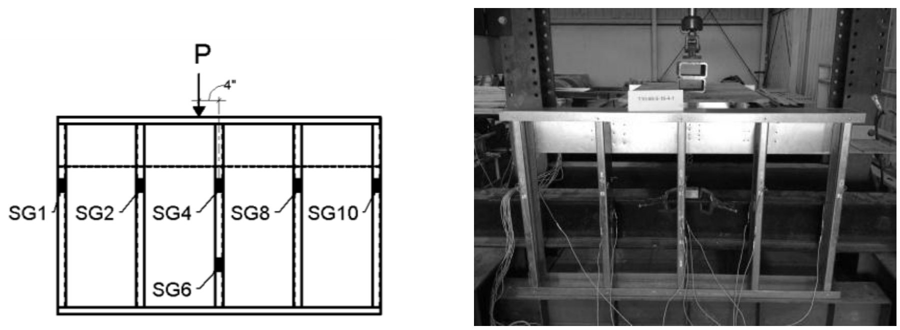
Test 2 – 4" Load Offset: was a five stud wall with the center joist loaded and the connector screws offset 4" from the center of the center stud.

Test 3 – 8" Load Offset: was a four stud wall with the center joist being loaded and the connector screws offset 8" with respect to the two adjacent center studs.

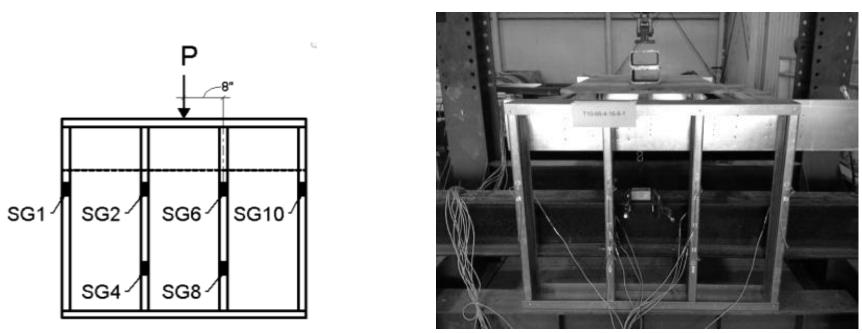
Ten millimeter strain gauges were adhered to the stud flanges and the center two studs had two strain gauges adhered to the compression flange and two to the tension flange. The top strain gauges were placed 14" from the top of the wall, whereas the bottom strain gauges were placed 10" from the bottom. Finally, a string pot was attached to the end of the joist at the connector to measure the deflection of the joist near the wall.



(a) Test 1 – Zero Load Offset



(b) Test 2 – 4” Load Offset



(c) Test 3 – 8” Load Offset

Figure 5 - Loading Cases with Strain Gauge Locations

Up to 12 channels of data (load, strain, displacement) were recorded electronically.

Observations and Analyses

The stud strain gauges were used to calculate the percentage of the joist reaction that was distributed to each stud in the wall panel for the three tests. Percent distribution versus total applied load (note, joist reaction is ½ the total load) is shown in Figure 6 through Figure 8.

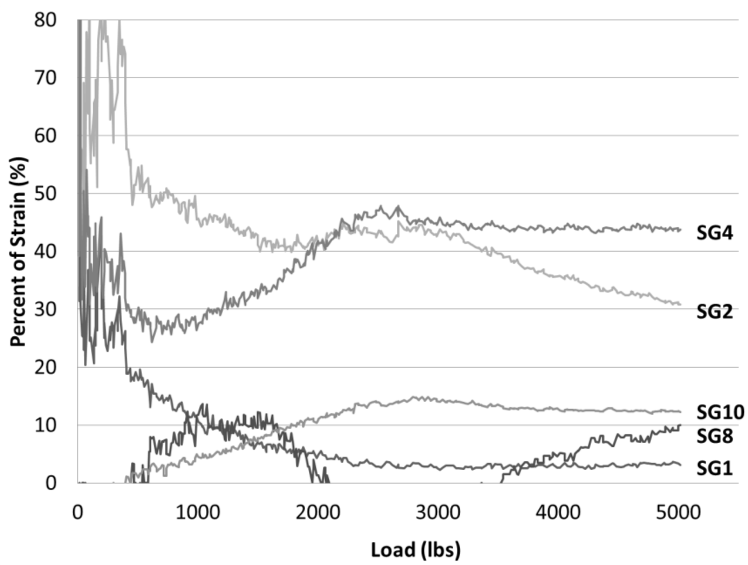


Figure 6 - Load Distribution Plot of Test 1 (Zero Load Offset)

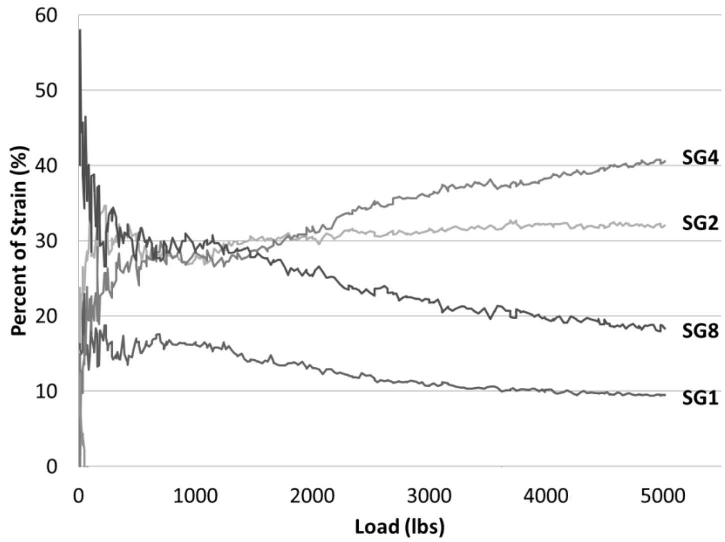


Figure 7 - Load Distribution Plot of Test 2 (4" Load Offset)

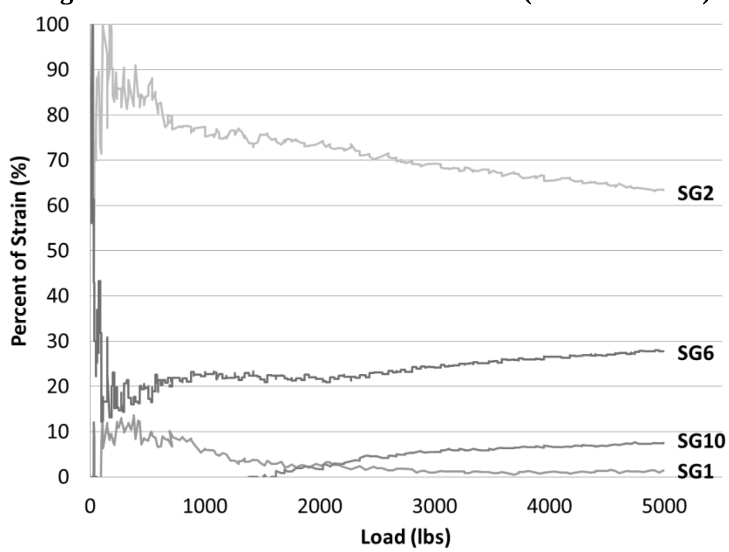


Figure 8 - Load Distribution Plot of Test 3 (8" Load Offset)

The typical load distribution was somewhat erratic at lower load levels, which can be attributed to the instrument resolution at the smaller strain levels. Once the strain readings increased, the load distribution changed more rapidly up to about 2000 lbs, at which point the load distribution became more consistent. It can be observed that the percent of strain distribution varied with increasing loads. This is counter intuitive to a typical static analysis and implies that second order effects continue to progress with higher loads. The tests were stopped when the joist reaction reached 2,500lbs (total load of 5,000lbs) since this is a typical joist reaction.

One can observe from Test 1 with no load offset that the assumption that 100% of the joist reaction is transferred to that stud is not valid. In fact, the track was able to distribute the load significantly in this case, resulting in only 43% of the joist reaction being transferred to the stud that it was directly connected to. This is due to the axial deformations in the studs (studs act as spring supports), which causes the track to bend and therefore distribute the load to adjacent studs as expected.

It is also of interest to note that, in the case of Test 3 with an 8" load offset, the two adjacent studs had significantly different load distributions (63% to one stud and 28% to the other). This is the result of the eccentric load introduced by the one sided connector used to connect the joist to the ledger track.

The strain gauge results were also used to calculate the moment induced as a result of the ledger track loading the stud flange. As such, the load is applied at an eccentricity equal to ½ the depth of the stud. A moment versus stud reaction plot of Test 1is shown in Figure 9. The measured moment was derived directly from the strain gauges. The expected moment, M_s, is taken as the stud reaction multiplied by the eccentricity, which in this case is 3". Finally, the "Conservative Moment" is taken as the measured joist reaction multiplied by the eccentricity.

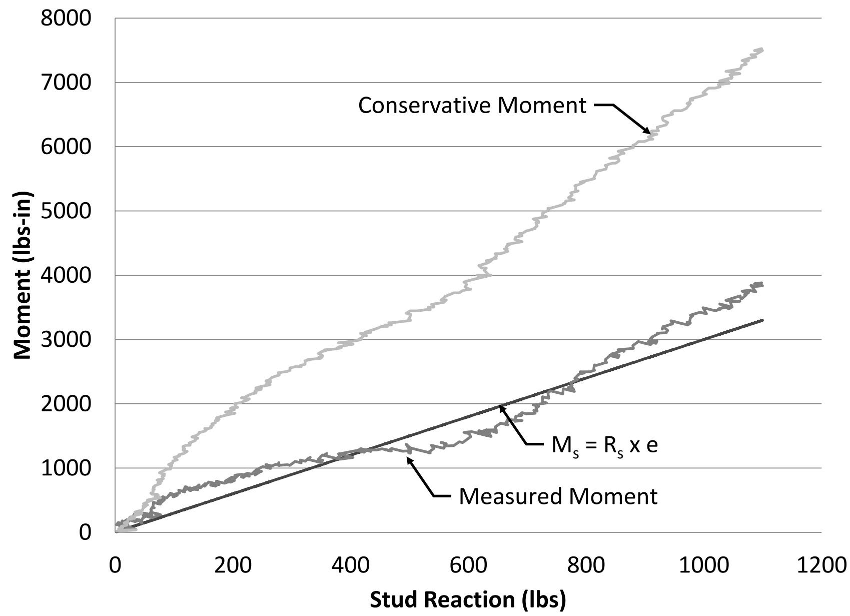


Figure 9 - Moment vs. Stud Reaction of Test 1 (Zero Offset)

It can be observed that the measured moment is in close agreement with the moment calculated on the basis of the measured stud reaction (taking into account the distribution) multiplied by the eccentricity. Further, it is observed that, even though the joist connector was directly connected to the stud, the measured moment is significantly lower than the “conservative moment” that would be expected on the basis of the full joist reaction.

Full Wall Analysis

In order to compare the tested values with both the unconservative and the analytical approach, a full wall analysis was carried out using the principle of superposition, as shown in Figure 10, using the load distribution values from the test data at a joist reaction of 2,500lbs. Each load, P_i, was taken as 100, and therefore the total stud reactions shown can be regarded as the percent distribution. The maximum calculated distribution is 76% of the joist reactions using this analysis. As per Eqn. (3), the expected percent distribution using the unconservative approach would be 67% [=16” / 24” x 100%], which is significantly lower than the measured value.

Load	P1			P2			P3			P4			P5			P6			P7
Stud #	1		2		3		4		5		6		7		8		9		10
STUD REACTION FROM P1	43		10		12														
STUD REACTION FROM P2	1		63		28		8												
STUD REACTION FROM P3			3		31		43		10		12								
STUD REACTION FROM P4							1		63		28		8						
STUD REACTION FROM P5									3		31		43		10		12		
STUD REACTION FROM P6													1		63		28		8
STUD REACTION FROM P7															3		31		43
SUM =	**44**		**76**		**71**		**52**		**76**		**71**		**52**		**76**		**71**		**51**

Figure 10 - Full Wall Analysis, Joists at 24” o.c. and Studs at 16” o.c.

A simple structural analysis was conducted as shown in Figure 11 using RISA-2D. The analysis resulted in a maximum stud load of 76% of the applied joist reaction, which is in agreement with the tested results. Interestingly, while one can observe the impact of the one sided connector in individual tests (as discussed above), this eccentricity did not affect the maximum stud reaction within the overall wall. This can be concluded given that this eccentricity was not considered in the RISA-2D analysis and the analysis was in good agreement with the test results.

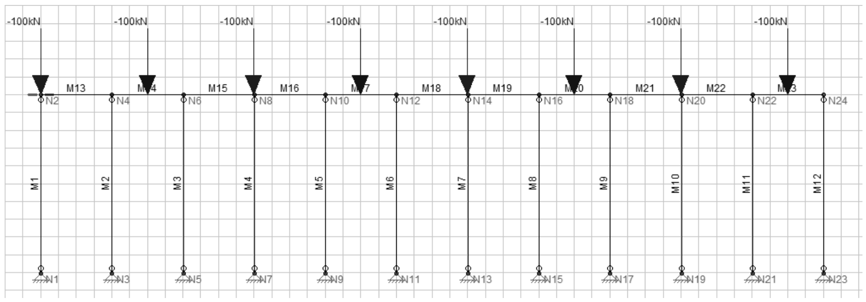


Figure 11 - Structural Analysis using RISA-2D

Summary

A test program was conducted to establish the load distribution capability of the 9 1/2", 0.0710" track section tested. It was observed that:

- the track section was able to distribute joist reaction to adjacent studs, even when the connection was centered directly on a stud,

- the moment induced by the eccentricity ledger connection reasonably agreed with the stud reaction multiplied by the eccentricity, and

- as expected, the distribution falls in between the conservative and unconservative approach for ledger framing analysis, and agrees with a simple structural analysis ignoring the effect of the eccentricity induced by the one sided connector.

Further testing is needed to fully establish a simple analysis procedure to quickly establish the coefficient, C, of Eqn. (5). Parameters that need to be varied should include different subfloor types, especially stiffer subfloors such as deck and concrete, different stud spacings, types and heights, as well as different ledger track types.

References

[1] AISI S200-07. "*North American Standard for Cold-Formed Steel Framing - General Provisions"*, 2007 Edition. American Iron and Steel Institute, Washington DC, June 2007.

[2] Fox, D.M., Schuster, R.M., and Strickland, M.R. "*iSPAN*™*, A Light Steel Floor System"*. Proceedings of the 18th International Specialty Conference on Cold Formed Steel Structures, Orlando, Florida, 2006.

Notations

e	Eccentricity (in.)
M_s	Calculated flexural strength of stud (lb-in.)
R_s	Force in stud (lbs)
R_j	Force in joist (lbs)
S_s	Spacing of studs (in.)
S_j	Spacing of joists (in.)